# A decade of MAX-DOAS observations in Asia & Russia (MADRAS) since 2007:

## Progress in OMI Tropospheric NO2 validation & synthetic analysis

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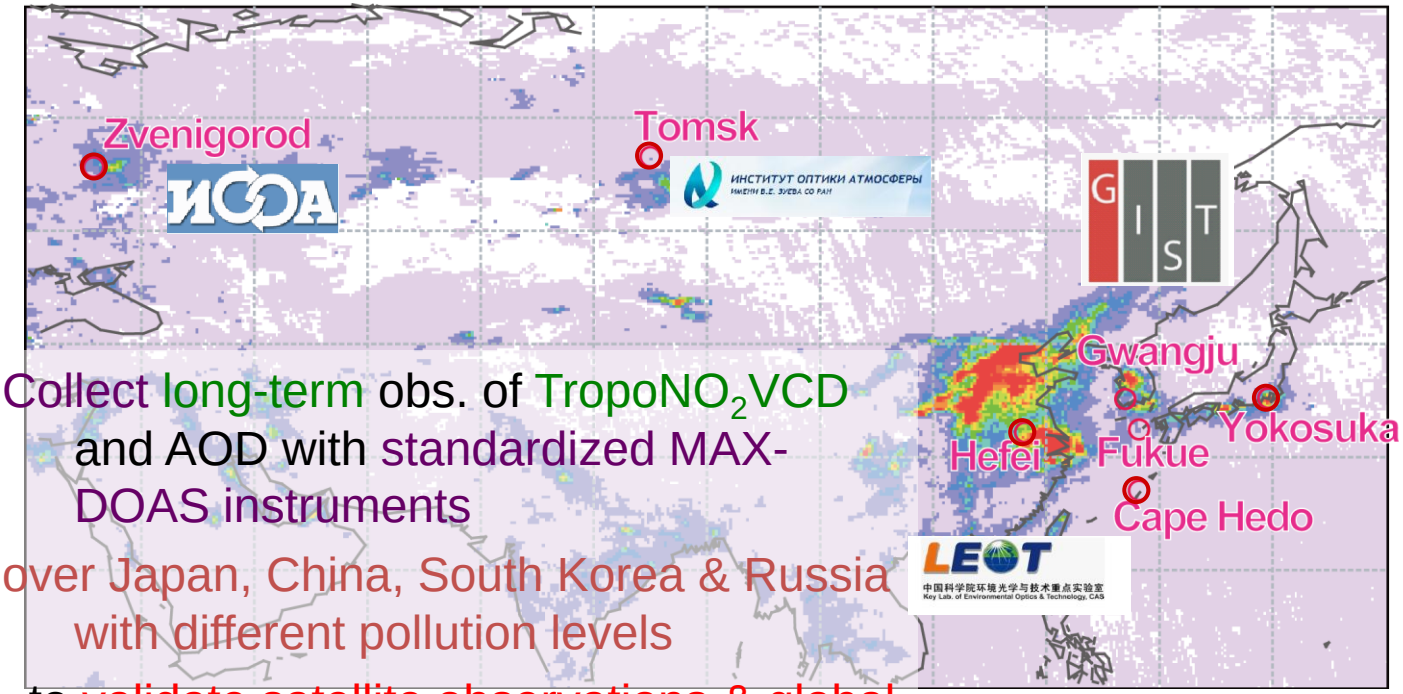
**[1] JAMSTEC,** [2]Chiba U., [3]Fukuoka U., [4]GIST, [5]Max Planck Institute, [6]Pukyong U., [7]AIOFM/CAS, [8]IAP/RAS, [9]Belarusian State U.




Collect long-term obs. of Tropo$NO_2$VCD and AOD with standardized MAX-DOAS instruments

over Japan, China, South Korea & Russia with different pollution levels

to validate satellite observations & global chemical transport model

**Kanaya et al. 2014; Irie et al., 2008a,b, 2011 etc, Takashima et al., 2009, 2011**

http://ebcrpa.jamstec.go.jp/maxdoashp/

# Principle of MAX-DOAS observations

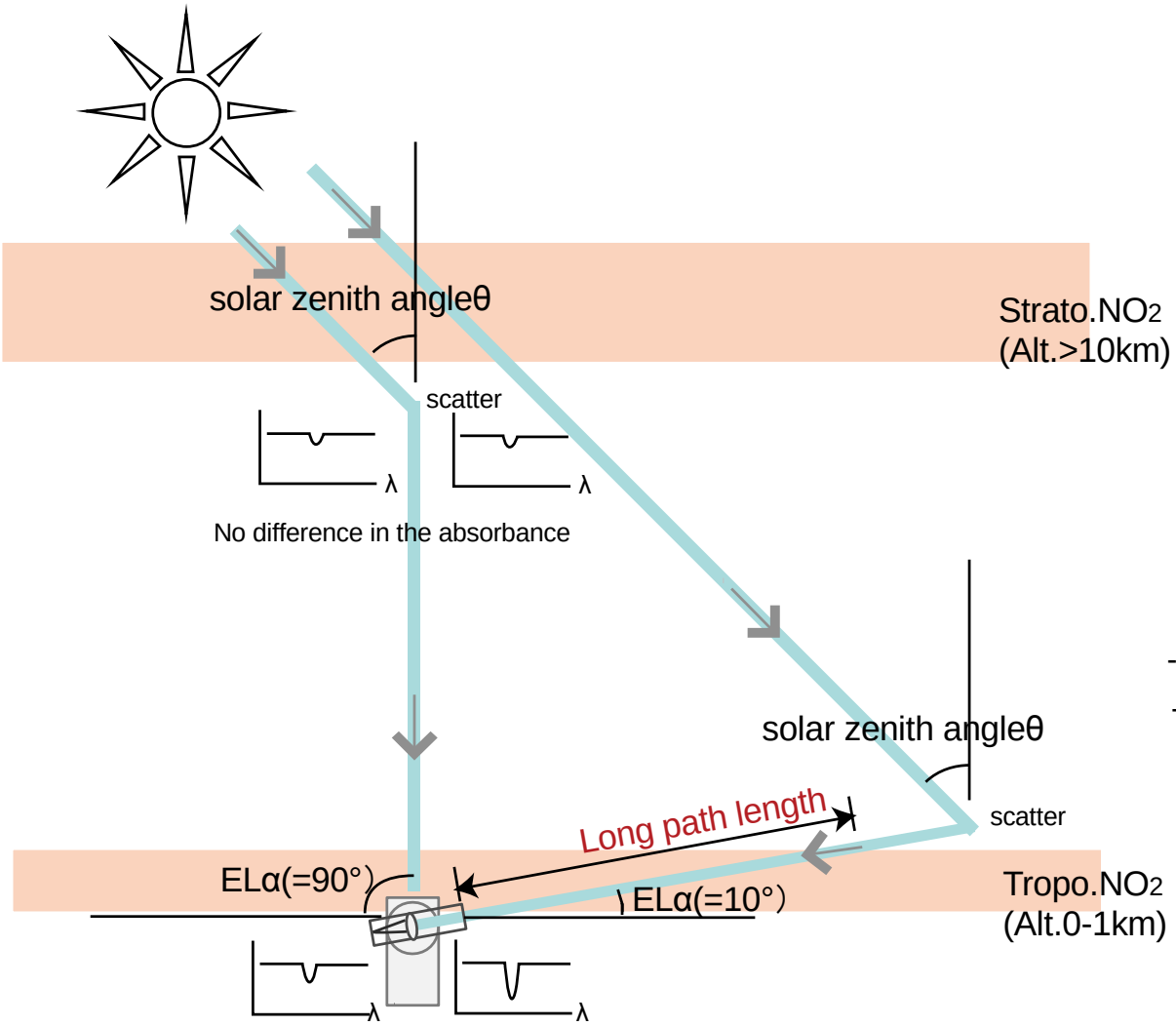
-MAX-DOAS: Multi-Axis Differential Optical Absorption Spectroscopy

Multiple axes: More information content than satellite (e.g., vertical profile)

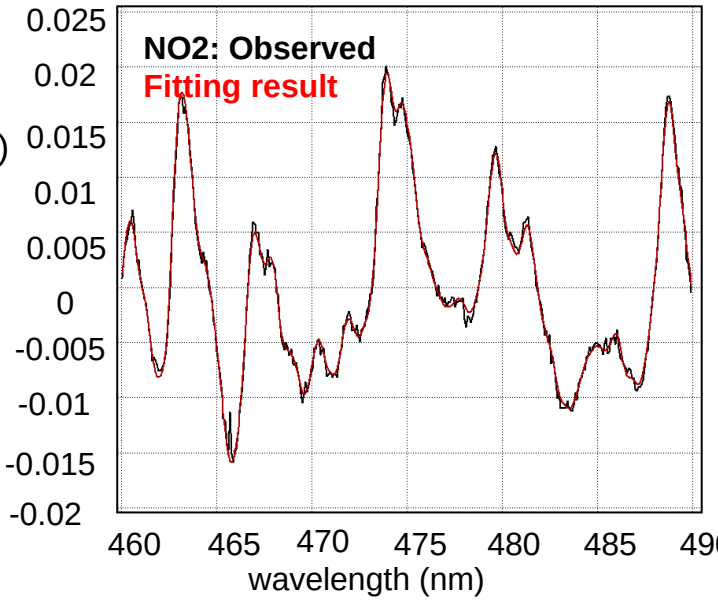
Simultaneous $O_4$ measurements: optical path length or aerosol (cloud) information

6 elevation angles (EA= 3º, 5º, 10º, 20º, 30º, 90º) are scanned;

1 cycle = 30 min (5 min x6 )




Larger absorbance for lower Elevation angles




# Retrieval algorithm

**Raw spectra**

**DOAS fitting using zenith spectrum "from the same meas. series" as reference**

$O_4$-DSCD for each EA

A priori AEC profile

$O_4$-DSCD derived from RTM

$O_4$-DSCD(obs)=$O_4$-DSCD(RTM)

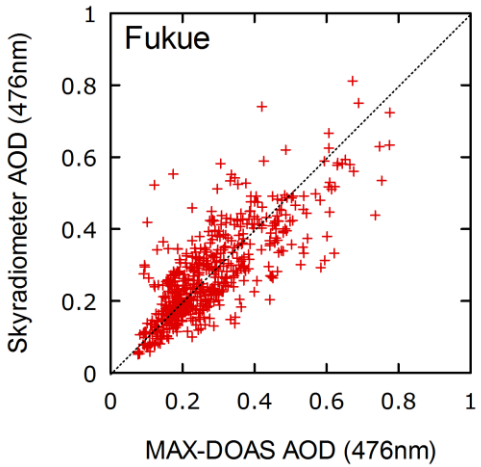
No

Yes

*Certified by intercomparis Wagner et al. (2007)*

**Revise AEC profile**

**Sinreich et al., 2005**




**Vertical profile of AEC, AOD**

A priori $NO_2$ profile

$NO_2$ –DSCD for each EA

$NO_2$-DSCD derived from RTM

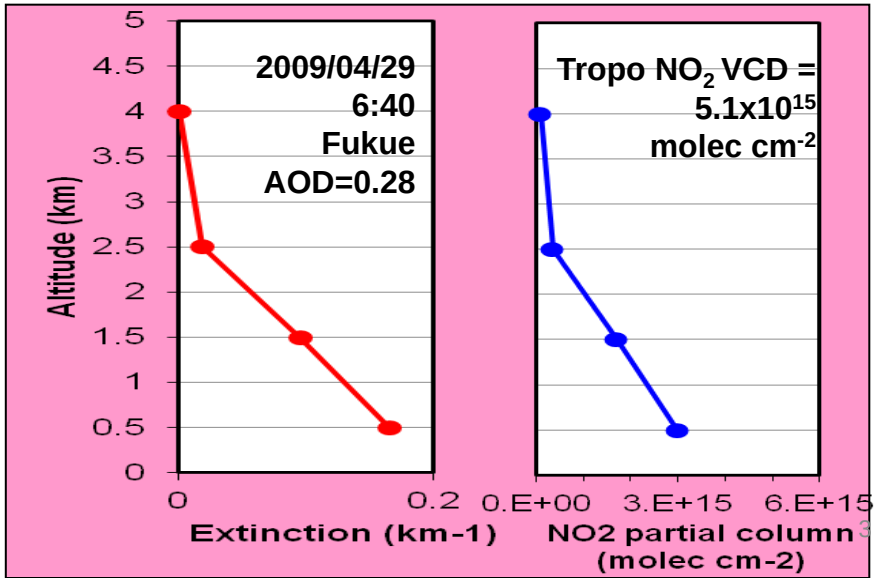
$NO_2$-DSCD(obs)=$NO_2$-DSCD(RTM)

No

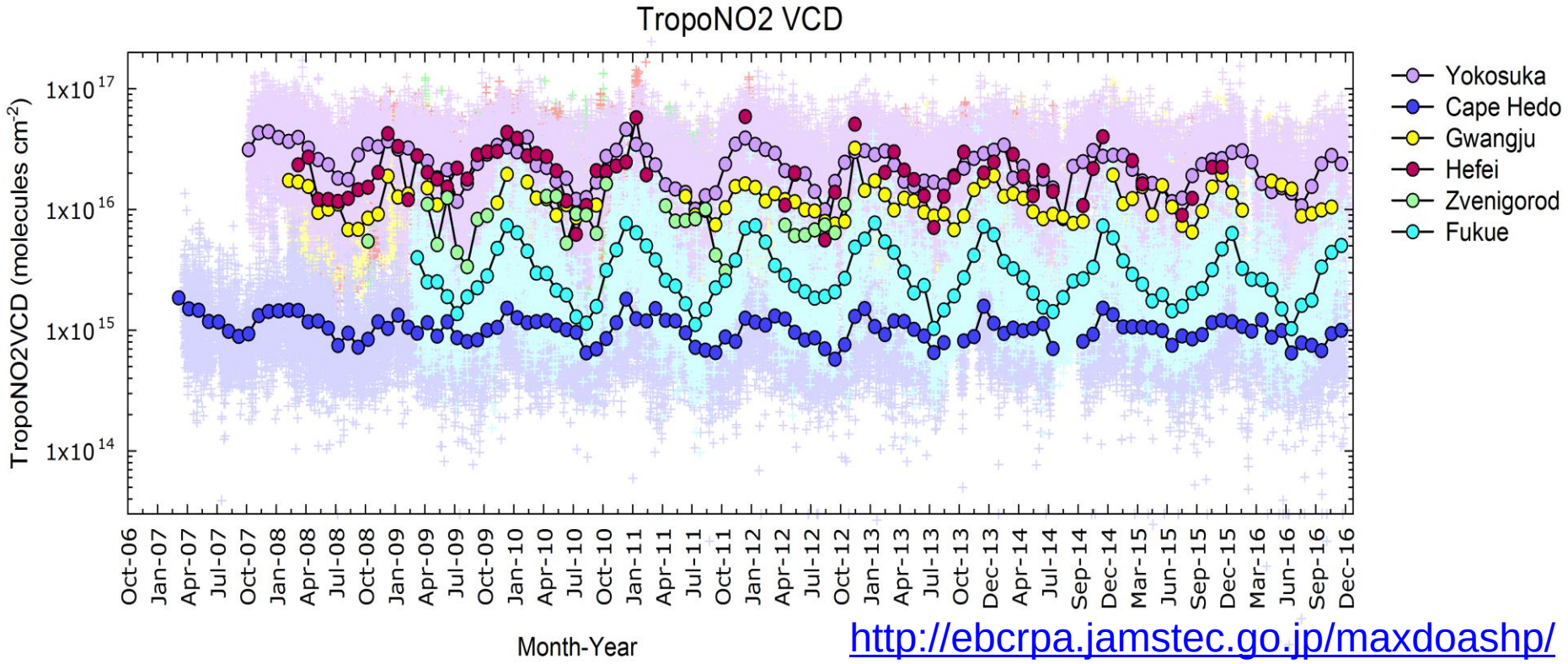
Yes

**Revise $NO_2$ profile**

**Vertical profile of $NO_2$, vertical column**




- Optimal Estimation Method *(Rodgers, 2000)*
  state vector: (TropoNO2VCD, $v_1$, $v_2$, $v_3$)
  ($v_1$: fraction of TropoNO2VCD present in the lowest 1km)
- Total uncertainty: 17%
  (even with 30% uncertainty in AOD)




http://ebcrpa.jamstec.go.jp/maxdoashp/

| | N (30 min) |
|---|---|
| Yokosuka | 45441 |
| Cape Hedo | 29814 |
| Gwangju | 21051 |
| Hefei | 7305 |
| Zvenigorod | 8946 |
| Fukue | 20198 |
| **TOTAL** | **132755** |

Data set

| site (latitude, longitude) | surface and instrument elevation (m, asl) | azimuth angle (N=0, E=90) | operation period | instrument no. | year | figures, recommendations |
|---|---|---|---|---|---|---|
| Yokosuka (35.32N, 139.65E) | | | | | | |

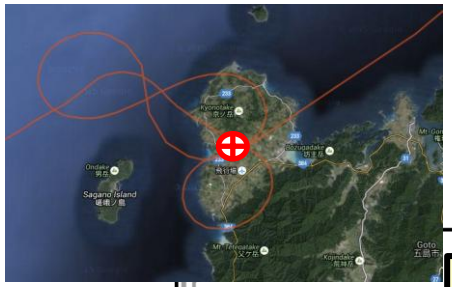
quality has not fully been understood yet. It is
recommended to contact Yugo Kanaya (yugo@jamstec.go.jp)
before use for publication. Please report a progress as
often as possible.

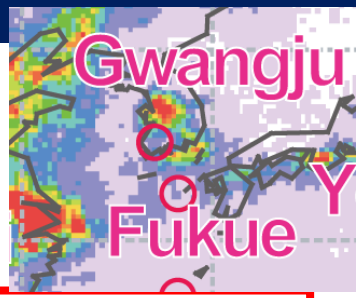
| doy[UTC] | year | fitresmax | AOD | AEC_L1[km-1] | AEC_L2[km-1] | AEC_L3[km-1] | NO2VCD[cm-2] | NO2_L1[cm-2] | NO2_L2[cm-2] | NO2_L3[cm-2] | T[K] | P[hPa] | CI | totalflag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.028461 | 2010 | 1.02E-03 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | 289.6 | 1021.0 | 2.528 | 00100001 |
| 1.049294 | 2010 | 1.06E-03 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | 289.6 | 1020.8 | 2.928 | 00100001 |
| 1.070127 | 2010 | 6.81E-04 | 4.478E-01 | | 1.658E-01 | | 2.383E-01 | | 3.504E-02 | | 8.328E+14 | | 5.030E+14 | |
| 1.090961 | 2010 | 8.11E-04 | 2.825E-01 | | 1.536E-01 | | 1.052E-01 | | 1.895E-02 | | 7.792E+14 | | 4.913E+14 | |
| 1.111794 | 2010 | 1.16E-03 | 3.193E-01 | | 1.645E-01 | | 1.269E-01 | | 2.235E-02 | | 6.803E+14 | | 4.082E+14 | |
| 1.132627 | 2010 | 7.51E-04 | 2.869E-01 | | 1.629E-01 | | 1.009E-01 | | 1.843E-02 | | 7.258E+14 | | 4.581E+14 | |
| 1.153461 | 2010 | 1.09E-03 | 3.779E-01 | | 1.954E-01 | | 1.506E-01 | | 2.547E-02 | | 4.676E+14 | | 2.883E+14 | |
| 1.174294 | 2010 | 8.34E-04 | 4.092E-01 | | 2.103E-01 | | 1.638E-01 | | 2.806E-02 | | 6.664E+14 | | 3.954E+14 | |
| 1.195127 | 2010 | 1.21E-03 | 3.679E-01 | | 1.757E-01 | | 1.605E-01 | | 2.528E-02 | | 6.370E+14 | | 3.944E+14 | |
| 1.215961 | 2010 | 5.72E-04 | 6.546E-01 | | 2.336E-01 | | 3.598E-01 | | 4.897E-02 | | 4.776E+14 | | 2.866E+14 | |
| 1.236794 | 2010 | 1.07E-03 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | 290.2 | 1019.0 | 2.282 | 00100001 |
| 1.257627 | 2010 | 1.08E-03 | 4.304E-01 | | 2.122E-01 | | 1.810E-01 | | 2.981E-02 | | 9.156E+14 | | 6.528E+14 | |
| 1.278461 | 2010 | 1.22E-03 | 3.863E-01 | | 2.144E-01 | | 1.398E-01 | | 2.573E-02 | | 5.787E+14 | | 3.535E+14 | |
| 1.299294 | 2010 | 2.17E-03 | 3.173E-01 | | 1.728E-01 | | 1.178E-01 | | 2.135E-02 | | -999.9 | -999.9 | -999.9 | -999.9 |
| 1.320127 | 2010 | 2.73E-03 | 3.516E-01 | | 1.991E-01 | | 1.235E-01 | | 2.324E-02 | | -999.9 | -999.9 | -999.9 | -999.9 |
| 1.965961 | 2010 | 1.79E-03 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | 291.3 | 1018.3 | 3.002 | 00100001 |
| 1.986794 | 2010 | 2.05E-03 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | 291.4 | 1018.2 | 2.717 | 00100001 |
| 2.007627 | 2010 | 1.50E-03 | 2.373E-01 | | 1.316E-01 | | 8.586E-02 | | 1.594E-02 | | 6.688E+14 | | 4.888E+14 | |
| 2.028461 | 2010 | 1.57E-03 | 3.130E-01 | | 1.700E-01 | | 1.161E-01 | | 2.157E-02 | | 6.799E+14 | | 4.123E+14 | |
| 2.049294 | 2010 | 1.45E-03 | 3.696E-01 | | 1.913E-01 | | 1.467E-01 | | 2.529E-02 | | 7.194E+14 | | 4.316E+14 | |
| 2.070127 | 2010 | 7.92E-04 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | 291.7 | 1017.1 | 2.711 | 00100001 |
| 2.090961 | 2010 | 8.64E-04 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | 291.8 | 1016.8 | 2.868 | 00100001 |
| 2.111794 | 2010 | 7.27E-04 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | 291.9 | 1016.4 | 2.662 | 00100001 |
| 2.132627 | 2010 | 9.55E-04 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | 292.0 | 1016.1 | 2.673 | 00100001 |
| 2.153461 | 2010 | 8.15E-04 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | 292.1 | 1015.8 | 2.947 | 00100001 |
| 2.174294 | 2010 | 6.85E-04 | 7.763E-01 | | 3.151E-01 | | 4.049E-01 | | 4.516E-02 | | 8.575E+14 | | 5.696E+14 | |
| 2.195127 | 2010 | 1.07E-03 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | 292.3 | 1015.1 | 2.920 | 00100001 |
| 2.215961 | 2010 | 1.61E-03 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | 292.4 | 1014.8 | 2.894 | 00100001 |
| 2.236794 | 2010 | 4.48E-03 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | -999.9 | 292.5 | 1014.4 | 2.875 | 00100001 |

| | | |
|---|---|---|
| | | 2.368E+14 |
| | | 4.268E+13 |

s recommended
nd extinction
recommended
nd extinction
2.41, and 1.55
nent 1, 2, and 3)
mended for AOD
tion profile.
2.1, and 2.02
nent 1, 2, and 3)
mended for AOD
tion profile.
and 2.01 (for
1 and 2) are

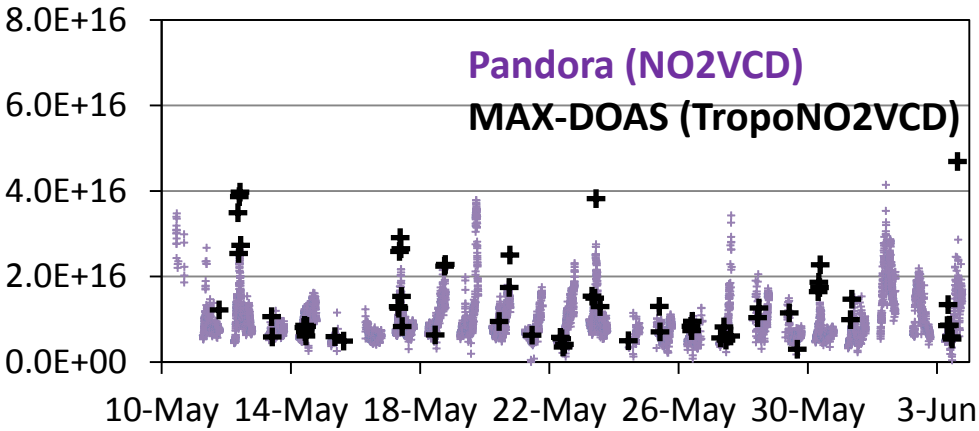
# Verification of MAX-DOAS $NO_2$ meas.: KORUS-AQ 2016

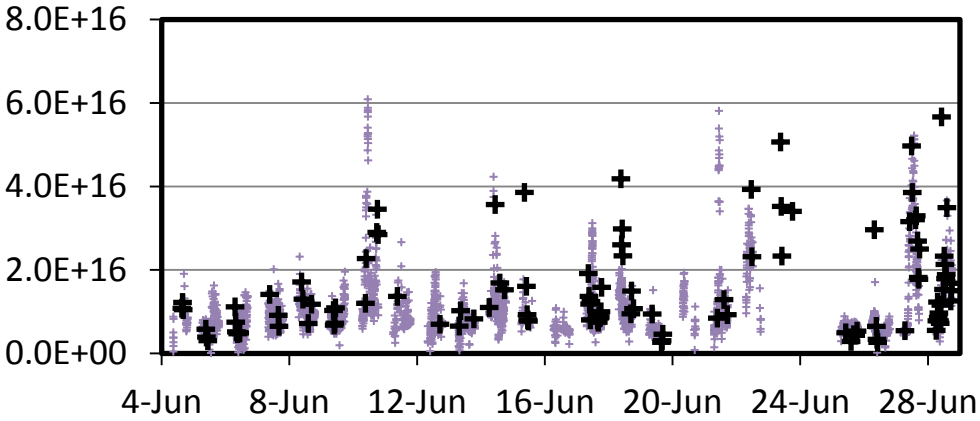





**Gwangju**

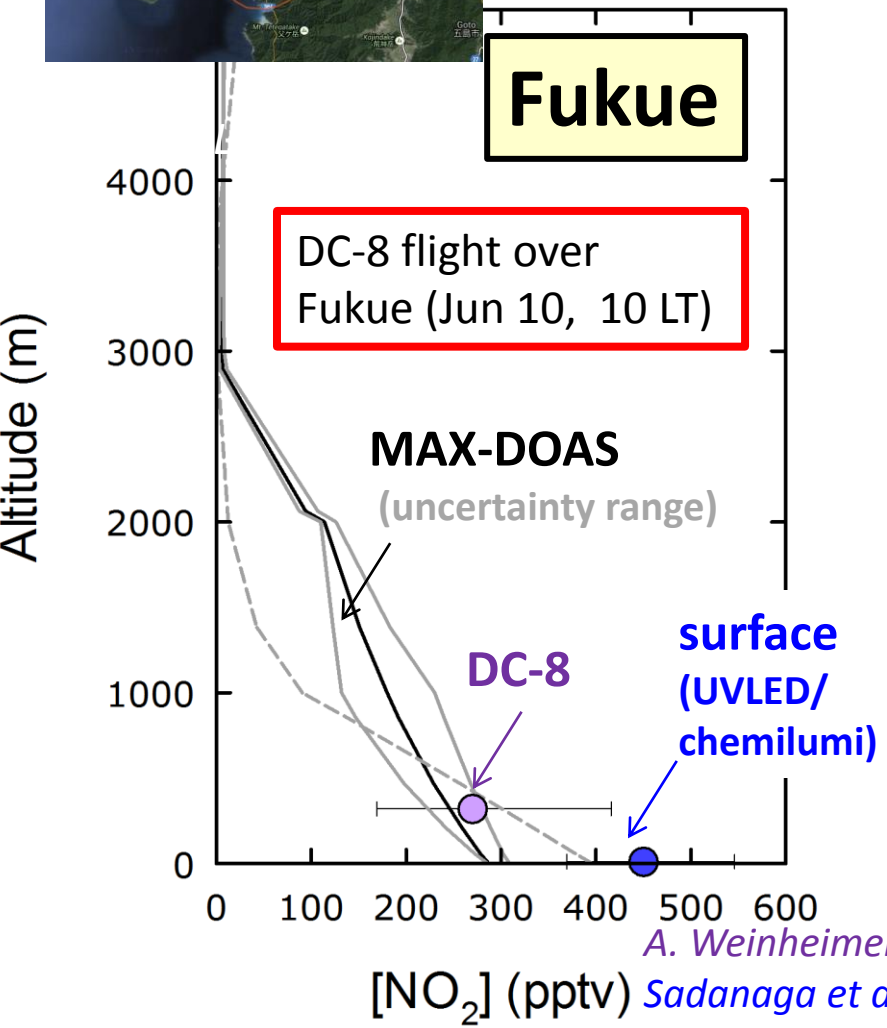
comparison with **Pandora 26** (preliminary)



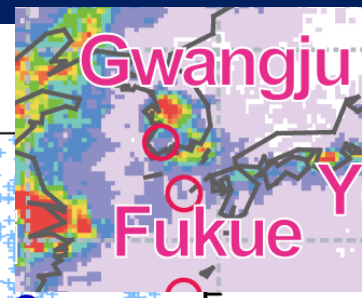

**Fukue**

DC-8 flight over
Fukue (Jun 10, 10 LT)



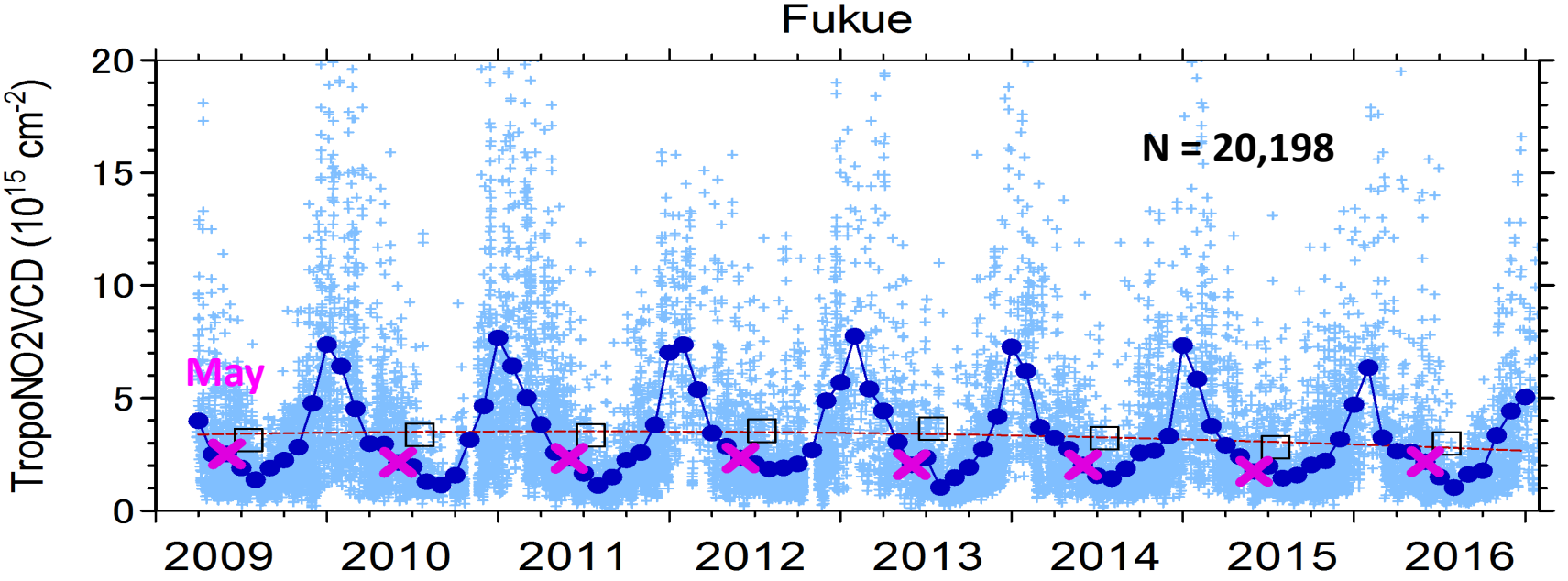

*A. Weinheimer, Sadanaga et al.*

# TropoNO2VCD at Fukue & Gwangju: Long-term variation



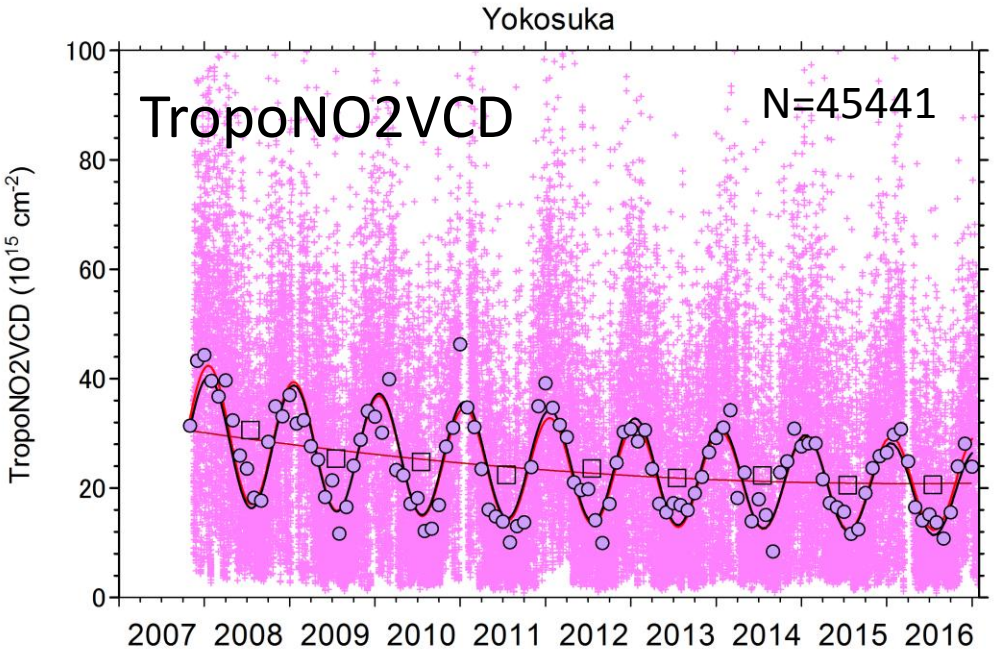


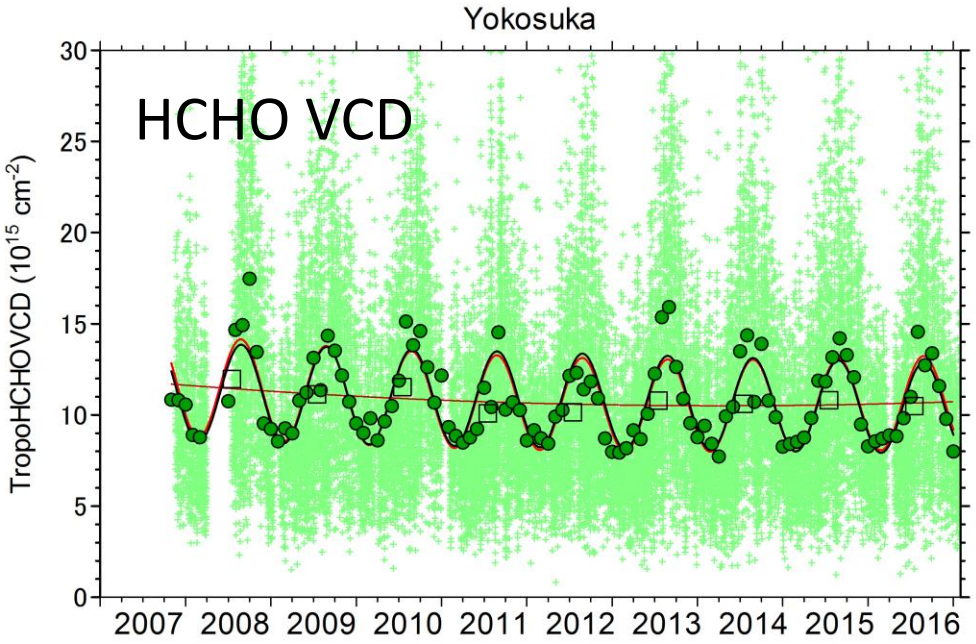




# Trend, Yokosuka (urban)

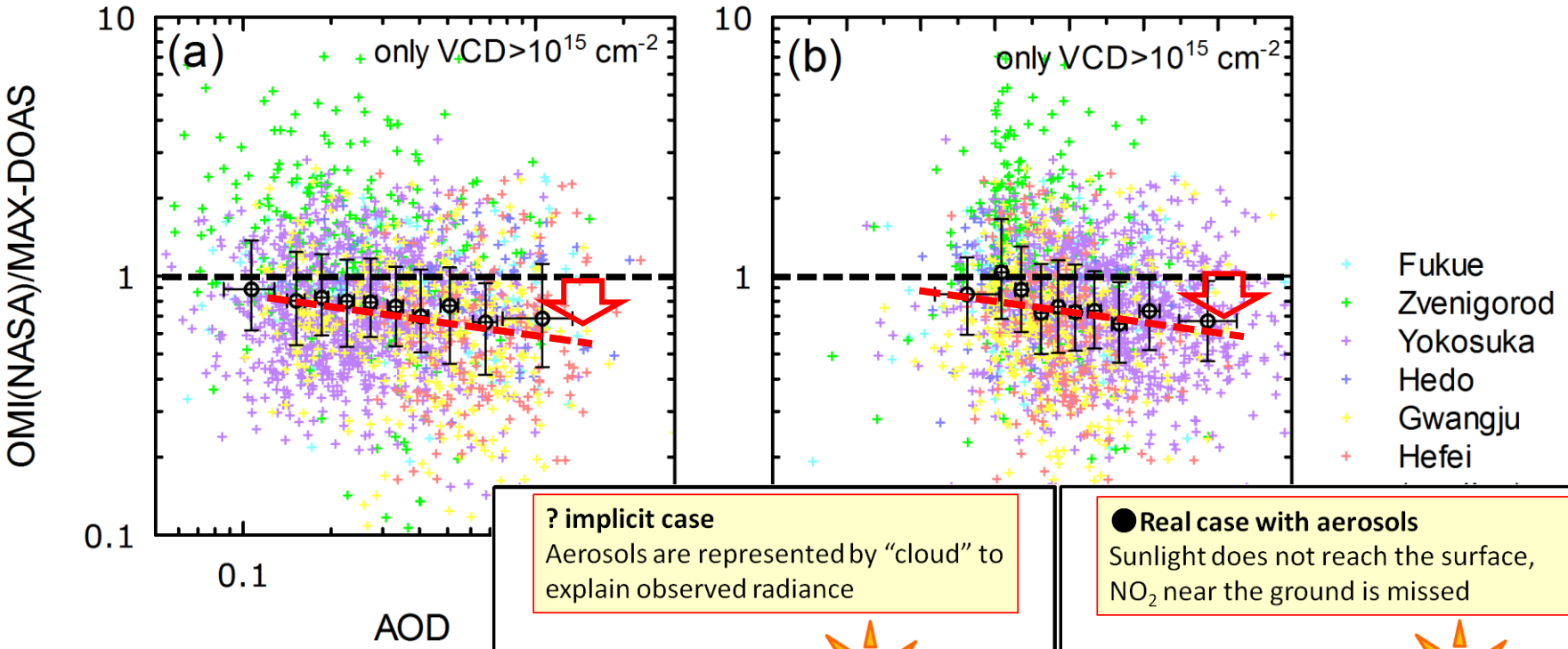
- Decrease in $NO_2$ levels, recently slowed
- HCHO flattened earlier and even increased in 2016.
- $O_3$ prod. regime would remain VOC-limited but shift toward NOx-limited side



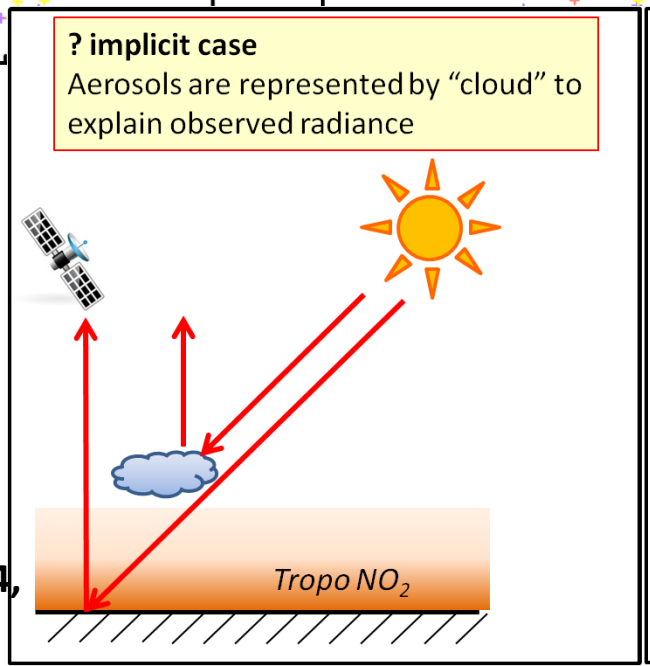



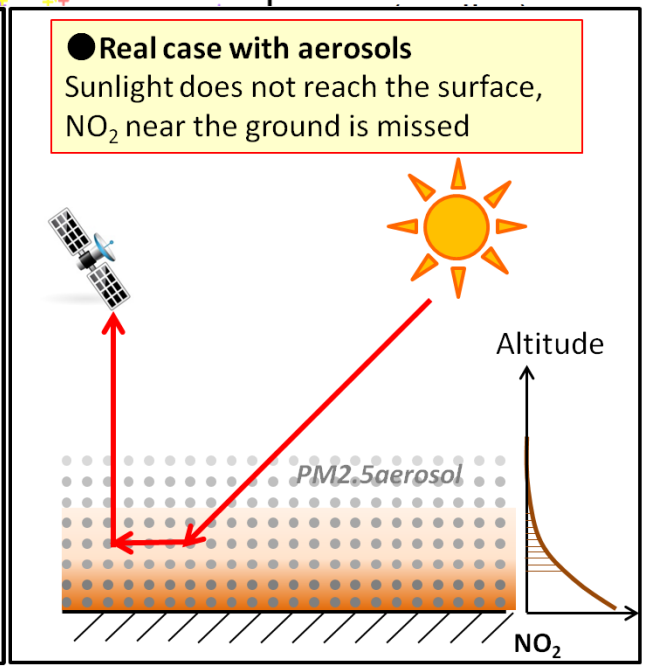
# OMI TropoNO2VCD validation: AOD & vertical profile shape dependence

## Aerosol shielding effect? (AK was not considered)




**(Kanaya et al., ACP,2014)**



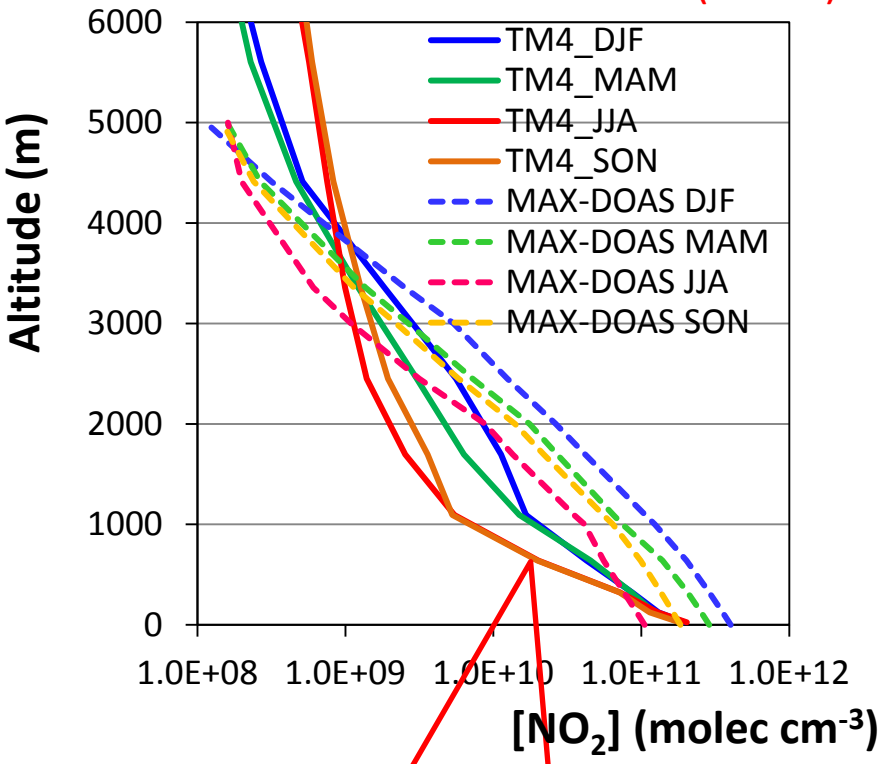



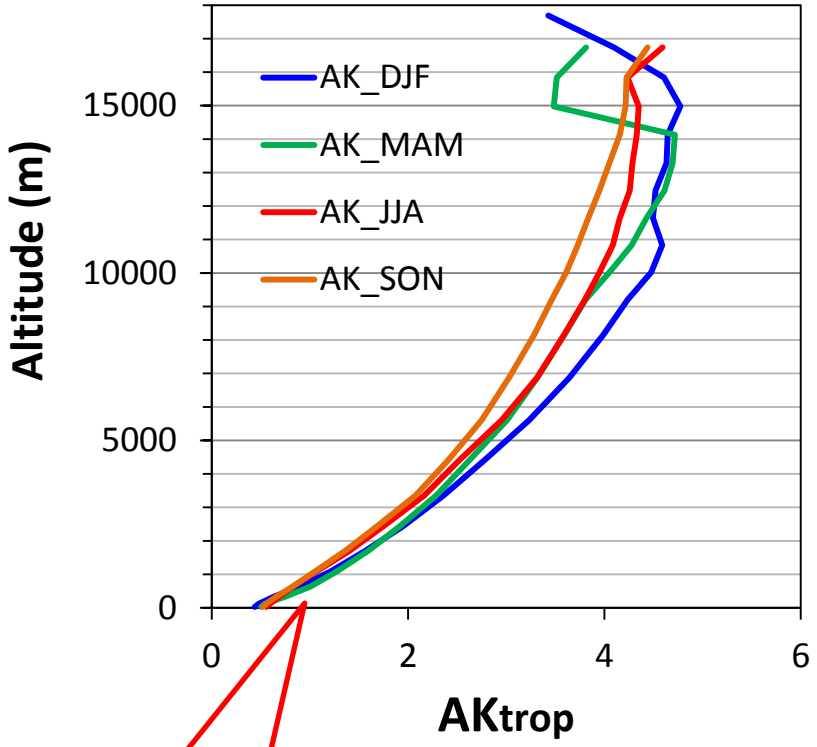

**(Kanaya et al., JAMSTEC press release 2014, KORUS-AQ white paper)**

# Renewed OMI DOMINOv2 TropoNO2VCD validation: Vertical profile shapes at Yokosuka (TM4 vs. MAX-DOAS)

**OMI DOMINOv2**, level2 data,
Δlat, long< 0.15°, Δt<1h, cloud fraction(cf) <0.3, Year= 2007-2014

Yokosuka (urban)



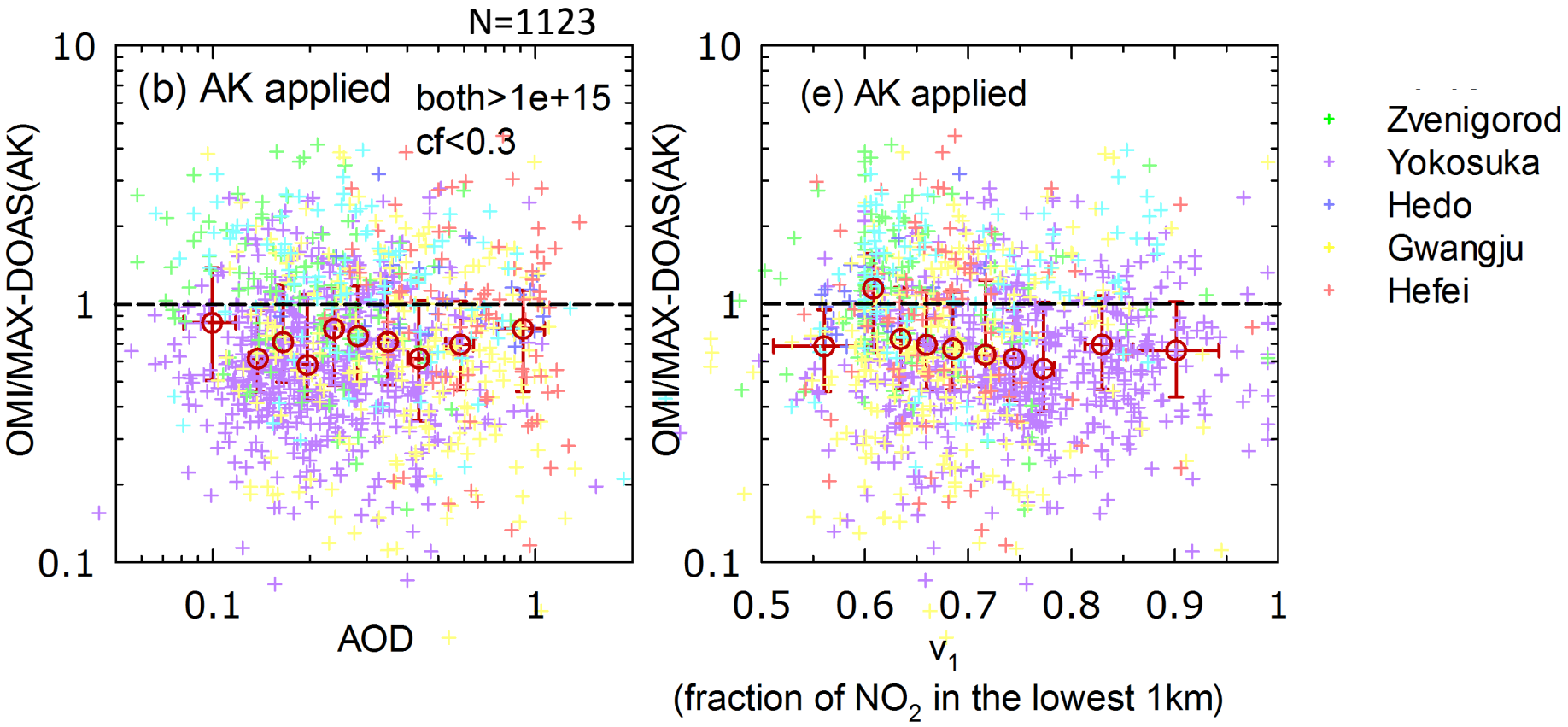

Rather steeper profile for TM4 than MAX-DOAS, despite coarse spatial resolution (2° x3°)

$AK_{Trop}$=0.5 near surface (for TM4 profile)

$$\mathbf{AK}_{\mathrm{trop}} = \mathbf{AK} \cdot \frac{AMF}{AMF_{trop}}$$

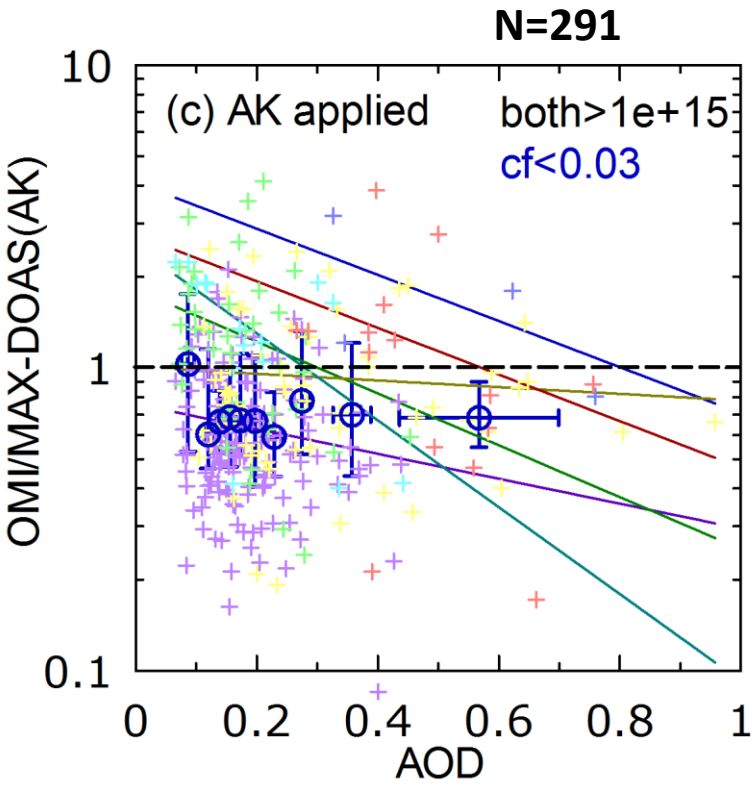
$$y_{trop} = \mathbf{AK}_{\mathrm{trop}} \cdot \mathbf{x}_{\mathrm{trop}}$$

# Renewed OMI DOMINOv2 TropoNO2VCD validation: with Averaging Kernel considered

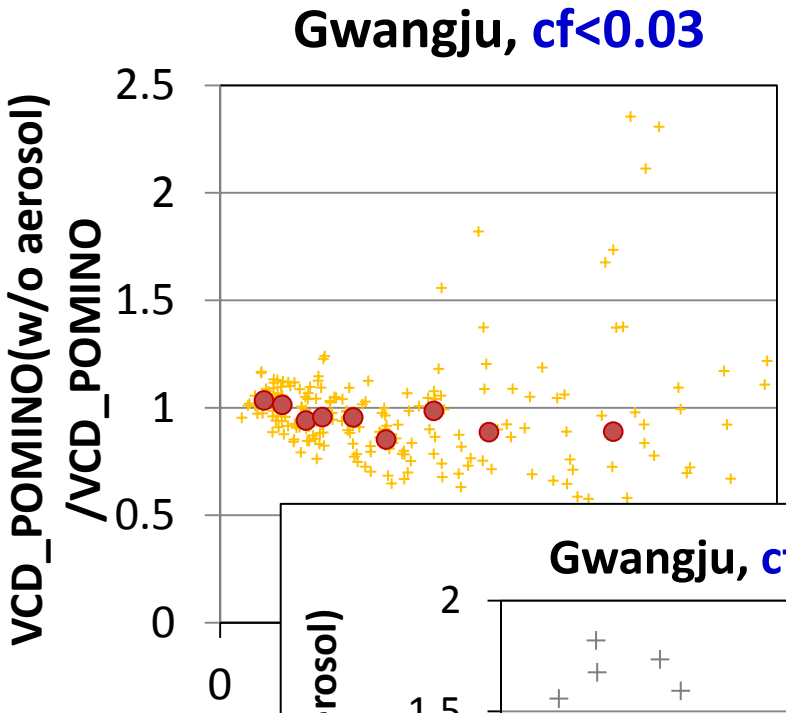



OMI/MAX-DOAS ratio got closer to unity, but OMI's underestimation remained.
Both dependence on AOD and $v_1$ slightly weakened.

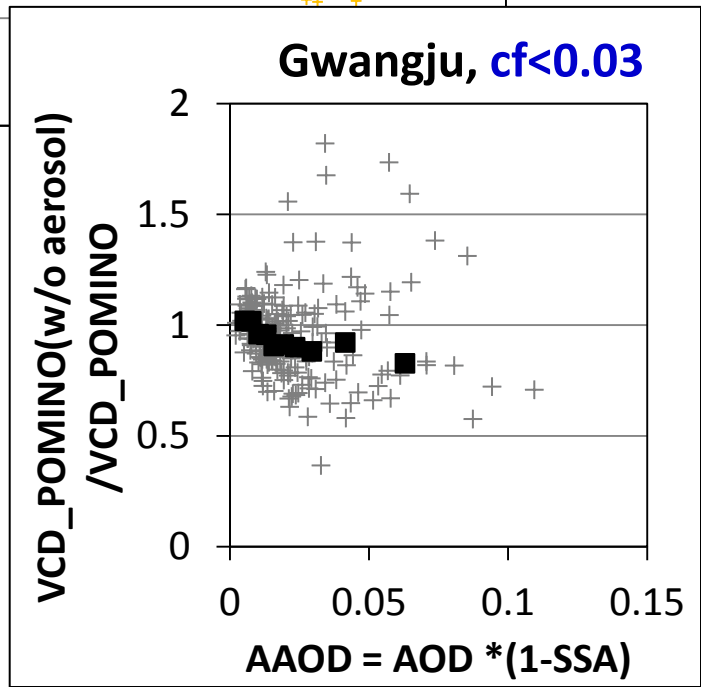
# AOD dependence (shielding effect) persisted with cf<0.03: consistent with theoretical calculations (POMINO)



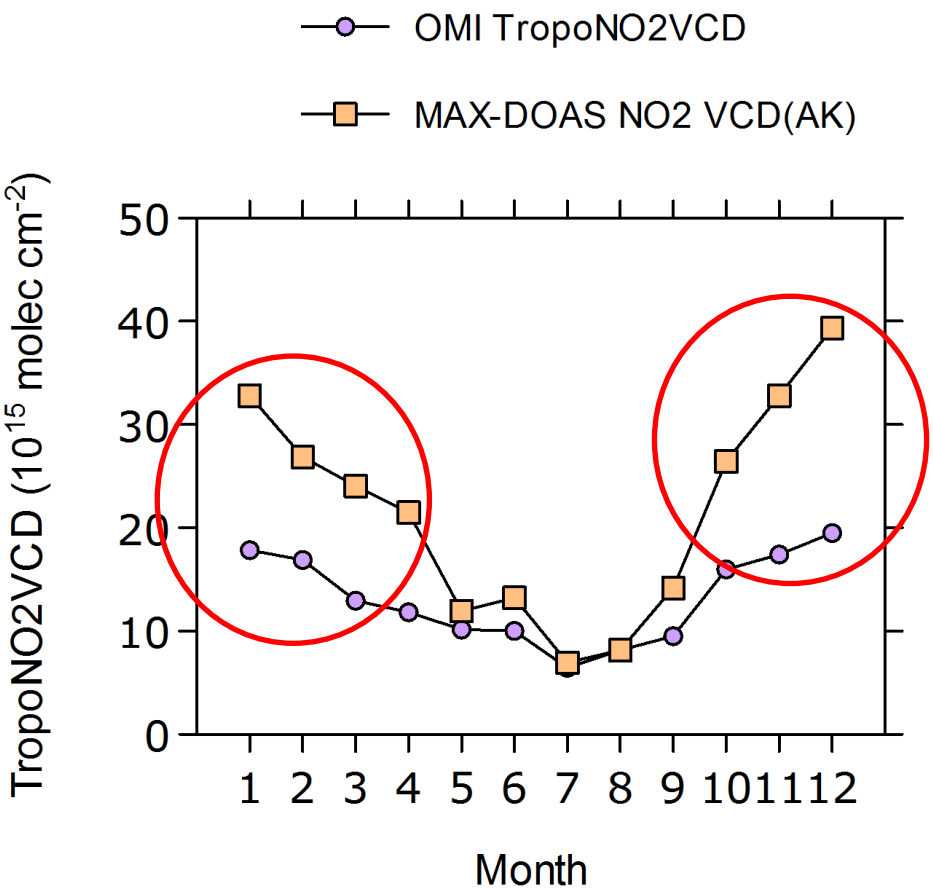

SSA, Aerosol Layer Height effects should also be examined.

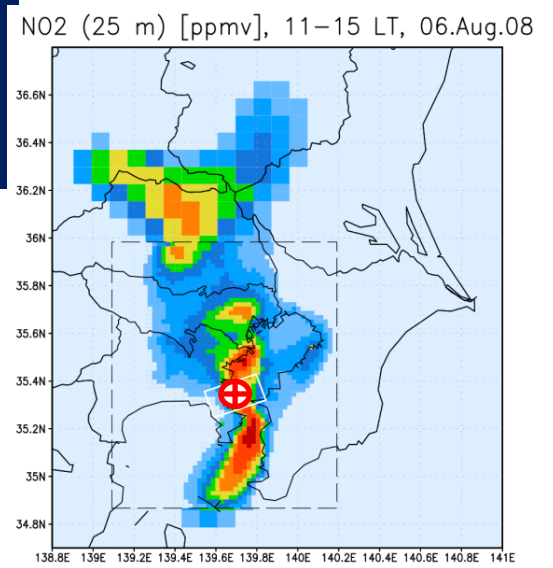


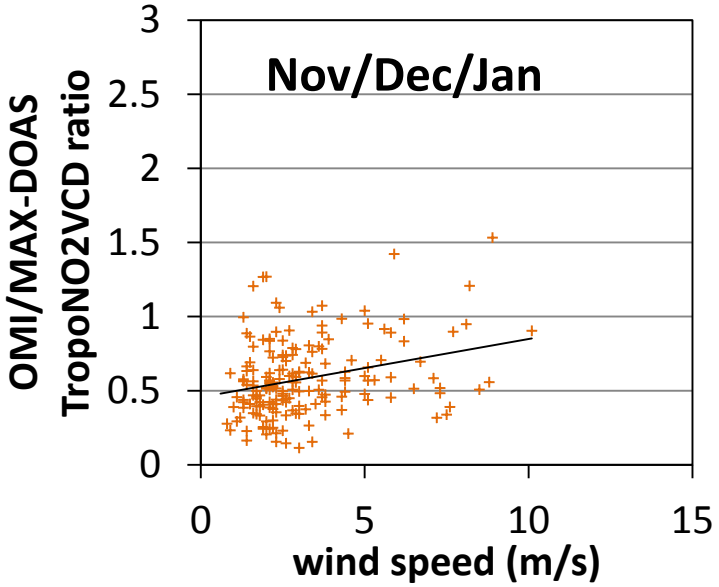

Data provided by Mengyao Liu, Jintai Lin (PKU)



# OMI-to-MAXDOAS comparison at Yokosuka: Significant gap remained during wintertime



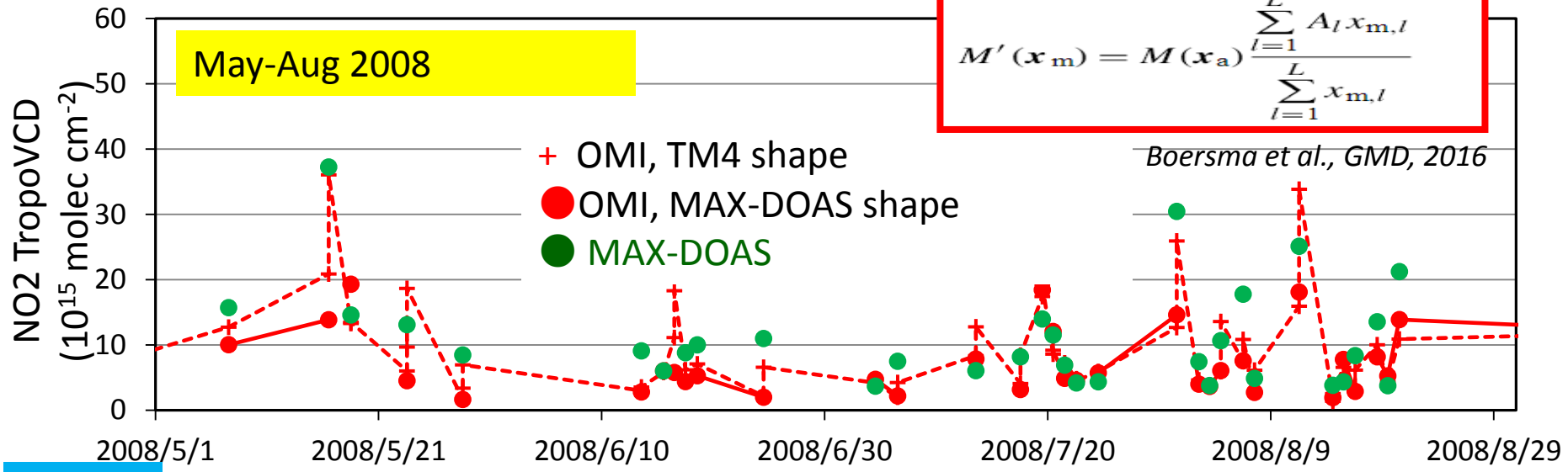

Significant gap in winter, associated with low wind speed.
Spatial inhomogeneity to be studied with TROPOMI

# OMI observes day-to-day variation (Yokosuka)

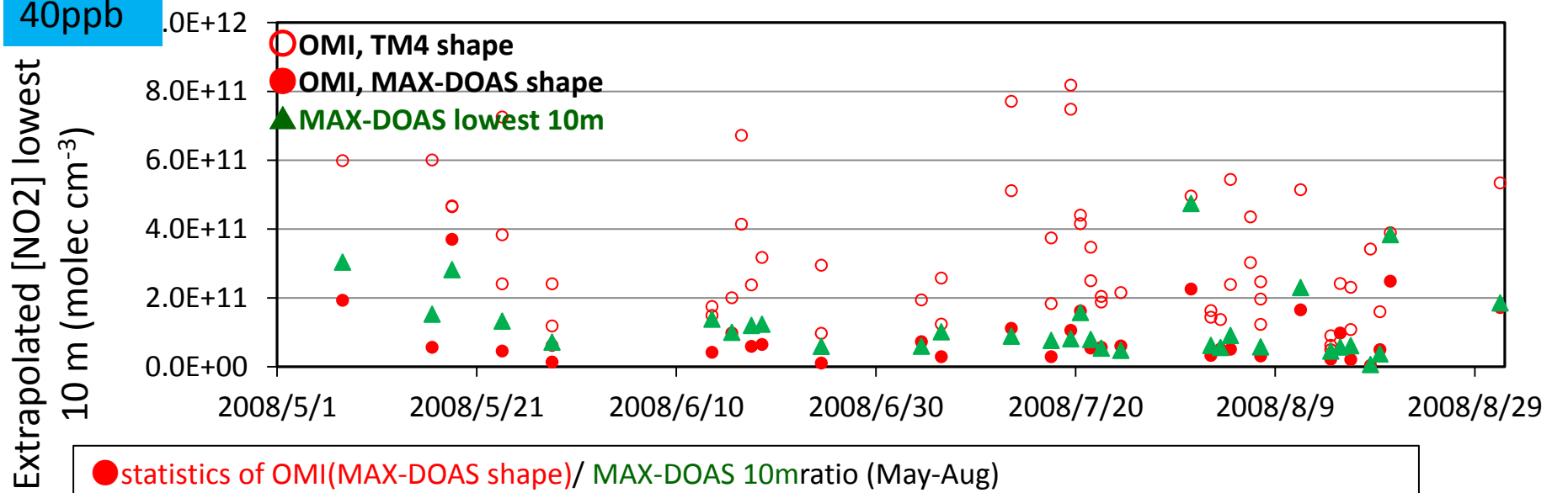
※OMI TropoVCD recalculated with MAX-DOAS shape

$$M'(x_m) = M(x_a)\frac{\sum_{l=1}^{L} A_l x_{m,l}}{\sum_{l=1}^{L} x_{m,l}}$$

*Boersma et al., GMD, 2016*




40ppb




●statistics of OMI(MAX-DOAS shape)/ MAX-DOAS 10mratio (May-Aug)
**median: 0.75** (25%tile 0.47, 75%tile 1.20)  n=162, r=0.71

# Summary

- MADRAS network continues to derive decadal variations in $NO_2$ & HCHO etc. and ground-truth into TROPOMI (ESA, NIDFORVal) & GEMS era.
- MAX-DOAS retrievals were evaluated during KORUS-AQ.
- Aerosol shielding effect: verified with clear sky data (cf<0.03) after AK applied.
- Fusion of MAX-DOAS and satellite obs. to derive surface $NO_2$: its variations were well captured from OMI satellite (May-Aug) at Yokosuka, when adequate vertical profile was inputted. Extrapolation to Kanto area map is ongoing.

*Acknowledgement*
*free use of tropospheric $NO_2$ column data from the OMI sensor from www.temis.nl, and from NASA. QDOAS software from BIRA-IASB.* Coordination Funds for Promoting AeroSpace Utilization, MEXT, Japan